SPECTAL STRUCTURE OF THE EARTH TIDES AND RELATED PHENOMENA : TILTMETRIC RECORDS

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SPECTRAL STRUCTURE OF THE EARTH TIDES AND RELATED PHENOMENA

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By

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Abstract

The spectral structure of the tiltmetric records obtained at Akibasan, Wakayama City in Japan, is discussed. The results of tidal analysis by the Fourier transform are compared with those by the method of least squares. Spectral features of long-period ranges up to 30 days are also investigated, and several prominent oscillations of the ground tilt with periods of 3.8, 6.0, 6.6, 8.4, 10.7, 13.2, 13.9, 16.7, 17.7, 18.9, 19.9, 25.3 and 28.7 days are found in the spectrum. Some of them are coincident with spectral peaks obtained from a gravimetric record.

1. Introduction

In the preceding part of the present study (Nakagawa et al. [1966]), the spectral structure of the gravimetric record observed at Kyoto was investigated by the Fourier transform method. The results gave fine spectra of the semidiurnal and diurnal tides, harmonic constants of the tidal constituents, and also some predominant spectral peaks with periods up to 30 days.

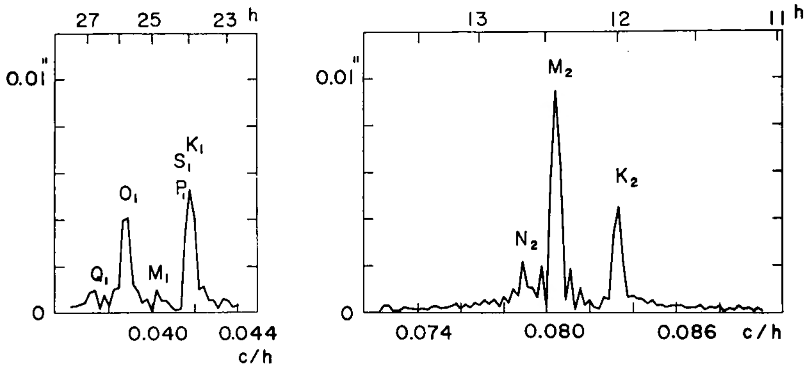
In the present part, the spectral structure of tiltmetric data is discussed from the same point of view as in the previous study. The main purpose is to get the spectrum of earth tidal phenomena included in observed tilts of the ground, and to obtain more information about the long-period oscillations which were detected in the gravimetric record. The procedure of numerical calculations is identical with that described in detail in the preceding part.

2. Data

The observation station is located at Akibasan, Wakayama City in Japan (34°12'N, 135°10'E, h=10 m). The photographic records of two tiltmeters of horizontal pendulum type oriented in the N-S and E-W directions (Tanaka [1964)] are analyzed. The period of analysis is one year from July 31, 15h00m, 1960 to July 31, 14h00m, 1961 (UT), which is just one year after that of the gravimetric observation. The sensitivities for both of the two components are about 0.004'' per 1 mm deflection on the records. The readings are made up to 0.1 mm at one hour interval, and the reading error is limited within 0.5 mm, which corresponds to a tilt of 0.002''.

3. Results and discussion

Fig. 1 shows the Fourier spectra of diurnal and semidiurnal oscillations of the N-S component tilt, which are obtained from 3 months' data from September 20, 15h00m to December 21, 14h00m, 1960 (UT). Since the resolution of the spectrum is related to the length of analyzed record, the separable fre-



Diurnal tides Semidiurnal tides

N-S component

Period of analysis : September 20, 15 : 00, 1960 - December 21, 14 : 00, 1960 (UT)

Fig. 1.

Table 1. Values of R and φ obtained from tiltmetric data (N-S component)

Method	Fourier transform		Least squares		Comparison	
	R_F (0.001'')	φ_F (degree)	R_L (0.001'')	φ_L (degree)	R_F/R_L	$\varphi_F-\varphi_L$ (degree)
M_2	9.332	21.33	9.291	21.20	1.004	+ 0.13
S_2	3.951	207.86	3.894	208.77	1.015	− 0.91
N_2	1.863	321.59	1.698	320.50	1.097	+ 1.09
K_2	0.957	328.36	1.031	329.23	0.928	− 0.87
K_1	5.761	334.33	5.724	334.03	1.006	+ 0.30
O_1	3.952	220.06	3.872	220.37	1.021	− 0.31
Q_1	0.716	136.36	0.651	134.41	1.100	+ 1.95
P_1	2.407	43.04	2.363	43.54	1.019	− 0.50

R : Amplitude of the constituent actually observed.

φ : Time interval from the origin time until the instant when the observed constituent actually reaches the maximum value.

Table 2. Values of R and φ obtained from tiltmetric data (E–W component)

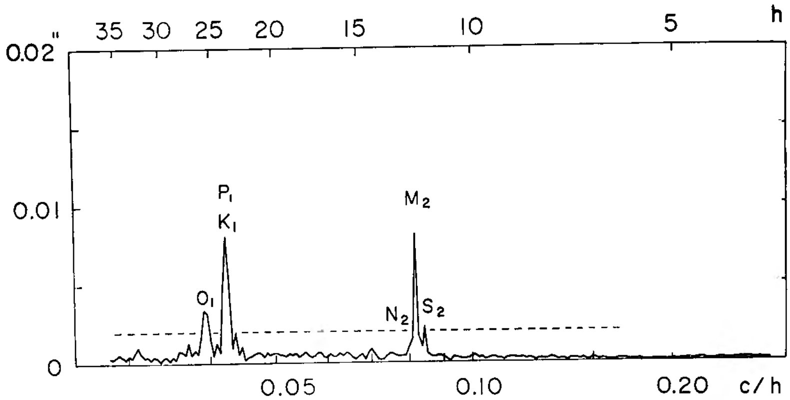
Method	Fourier transform		Least squares		Comparison	
	R_F (0.001″)	φ_F (degree)	R_L (0.001″)	φ_L (degree)	R_F/R_L	$\varphi_F-\varphi_L$ (degree)
M_2	16.625	10.28	16.549	10.02	1.005	+ 0.26
S_2	5.736	184.13	5.639	185.45	1.017	− 1.32
N_2	3.523	312.56	3.251	310.96	1.084	+ 1.60
K_2	2.148	290.95	2.288	291.37	0.939	− 0.42
K_1	6.888	316.40	6.817	316.31	1.010	+ 0.09
O_1	7.190	215.34	7.110	216.74	1.011	− 1.40
Q_1	1.249	170.25	1.126	169.80	1.109	+ 0.45
P_1	1.945	50.78	1.936	52.85	1.005	− 2.07

quency is limited to 0.0008 c/h in the present case. For this reason, one can not distinguish some groups of tidal constituents such as S_2 and K_2 which are closely spaced. As described in the preceding part, however, the amplitude and phase spectra of some major constituents can be estimated, when one year's data are used for the analysis.

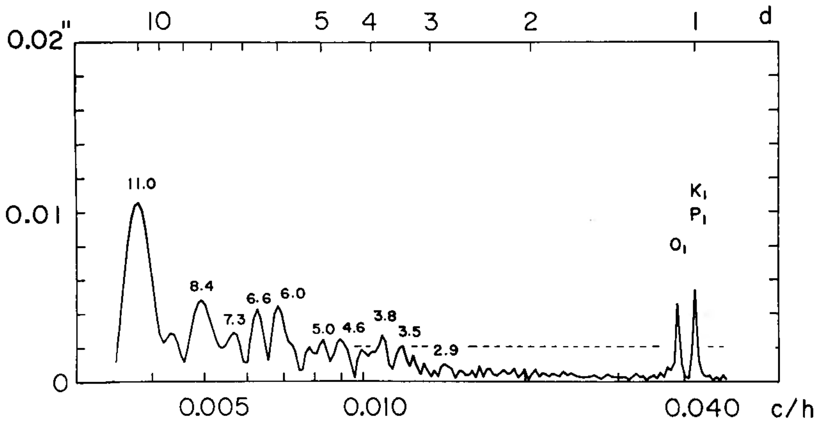
As a next step to this study, the amplitudes and phases of 8 principal constituents; namely, M_2, S_2, N_2, K_2, K_1, O_1, Q_1 and P_1, have been determined by the Fourier transform, using the full year data. Integrations were made only for their theoretically known angular velocities in the same way as in the gravimetric analysis. The results are shown in Tables 1 and 2, together with the corresponding harmonic constants obtained from the same data by the method of least squares. As the present station is very close to the coast, indirect effects of the oceanic tides seem to occupy the greater part of tidal tilting motion of the ground. Therefore, it would be insignificant to calculate the diminishing factor directly from the observations. The amplitudes, R_F and R_L, given in the tables are those for the constituents actually observed, and the phases, φ_F and φ_L, are the time intervals from the origin time (July 31, 15h00m, 1960) until the instant when the observed constituents actually reach the maximum tilt to south or east.

As can be seen in the tables, the amplitudes and phases, especially for 4 major constituents, M_2, S_2, K_1 and O_1, determined by the Fourier transform are in excellent agreement with those by the least squares method. It is noticed, however, that there are some systematic differences between the results from the two methods. For both components, the amplitude of K_2-constituent by the present method is smaller than that by the latter, and the phases for M_2-, N_2-, K_1- and Q_1-constituents show advances compared with those by the least squares. It appears that these discrepancies cannot necessarily be attributable to the effect of drift but partially to methodical differences, because the form of drift caused mainly by meteorological changes such as rainfalls, temperature and atmospheric pressure variations, is quite different for the N-S and E-W components.

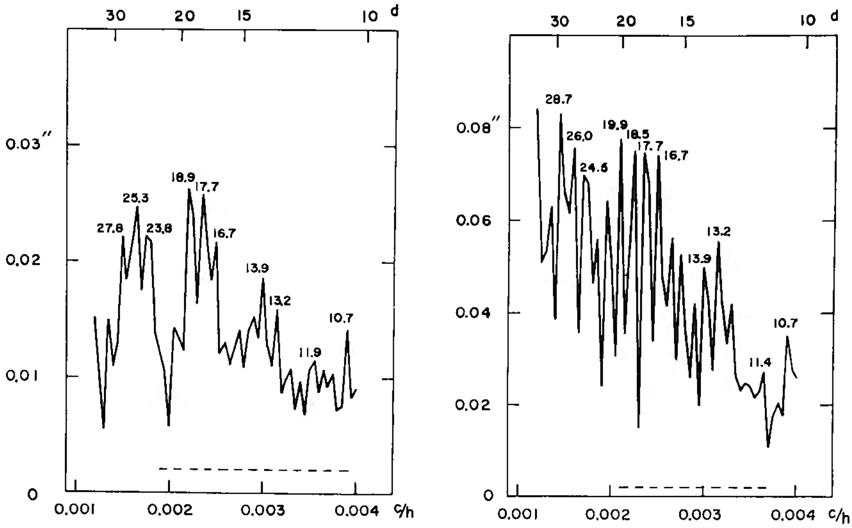
The spectral structure of tilting motion with long-periods from 3 hours to 30 days is investigated in the following. Fig. 2 shows the spectrum of the N-S component in the periods from 3 to 35 hours, calculated from 50 days' data from May 5, 15h00m to June 24, 14m00h, 1961. No prominent spectral peak, except for the groups of diurnal and semidiurnal tides, is seen in this range, although noise level increases gradually as the period of oscillation be-



N-S component
Period of analysis : May 5, 15 : 00, 1961 June 24, 14 : 00, 1961 (UT)
Fig. 2.



N-S component
Period of analysis : September 20, 15 : 00, 1960 – December 21, 14 : 00, 1960 (UT)
Fig. 3.



Period of analysis: July 31, 15:00, 1960 - July 31, 14:00, 1961 (UT)

Fig. 4.

Table 3. Prominent long-period modes recorded by tiltmeters

N–S component		E–W component		Remarks	
Period (day)	Amplitude (second)	Period (day)	Amplitude (second)	N–S	E–W
27.8	0.0222	28.7	0.0833		
25.3	0.0228	26.0	0.0759		
23.8	0.0222	24.5	0.0699	G	
		19.9	0.0779		G
18.9	0.0263	18.5	0.0550		G
17.7	0.0258	17.7	0.0742		
16.7	0.0217	16.7	0.0750		
13.9	0.0186	13.9	0.0500	G	G
13.2	0.0159	13.2	0.0556		
11.9	0.0116	11.4	0.0272	G	
10.7	0.0142	10.7	0.0349		
11.0	0.0105			G	
8.4	0.0047			G	
7.3	0.0028			G	
6.6	0.0042				
6.0	0.0044				
5.0	0.0024				
4.6	0.0025			G	
3.8	0.0027			G	
3.5	0.0020				
2.9	0.0010			G	

G: The corresponding period is also found from the gravimetric record.

comes longer. The spectrum in the period ranges from 1 to 12 days, obtained from 3 months' data of the same component tilt from September 20, 15h00m to December 21, 14h00m, 1960, is shown in Fig. 3. The spectral amplitudes become conspicuously larger in longer periods than 3 days. Some prominent peaks are found in this range. The full year data of the N-S and E-W components have also been analyzed to get the Fourier spectra for long-period oscillations with 10 to 30 days. The results are shown in Fig. 4, and the periods and amplitudes for prominent peaks are summarized in Table 3.

The fortnightly constituents *Mf* (13.66 days) and *MSf* (14.77 days) cannot be detected from the spectra, but this may be due to the geographical situation of the present station. The noise level of the E-W component is higher than that of the N-S, as seen in Fig. 4. This is considered to be caused by the difference in effects of meteorological disturbances, since the E-W component tilt at Akibasan is more disturbed by them than the N-S component (Tanaka [1964]).

It is interesting that several peaks common to both components can be seen in Fig. 4, and that some of them are coincident with those detected by the analysis of the gravimetric record. However, further investigations are necessary to make sure the origin of these significant oscillations. The analysis of observed records of oceanic tides, temperature and atmospheric pressure variations is under way to examine correlations of the tilting motions with these phenomena.

4. Conclusion

Tidal analysis of tiltmetric records has been carried out by the Fourier transform method. A comparison of the results with those by the least squares method shows good agreement. The present method has been effectively used for a spectral analysis, as well as for the usual tidal analysis with a sufficient accuracy if one year data are analyzed, even if a large drift was contained in the records. It was found that several predominant peaks exist in the spectra for long-period ranges. The principal tilt oscillations are of periods with 3.8, 6.0, 6.6, 8.4, 10.7, 13.2, 13.9, 16.7, 17.7, 18.9, 19.9, 25.3 and 28.7 days, although the origins of these phenomena remain unsolved.

References

Blum, P. A., J. Corpel, R. Gaulon, G. Jobert and J. P. Nieres, 1964 ; Rapport sur l'activite de l'Institut de Physique du Globe de Paris dans le domaine des marées terrestres, Communications de l'Observatoire Royal de Belgique **236**, Série Géophysique **69**, 172-177.

Nakagawa, I., T. Mikumo and T. Tanaka, 1966 ; Spectral structure of the earth tides and related phenomena. Gravimetric record, Spec. Contr. Geophys. Inst., Kyoto Univ., 6, 215–223.

Tanaka, T., 1964 ; Study on the relation between local earthquakes and minute ground deformation. Part 1, Bull. Disaster Prevention Res. Inst., Kyoto Univ., 14 (1), 55–77.